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Academic Level and Gender-based Mapping of High School Student's Genetic Literacy: A Cross Sectional Study in Indonesia

Nivel académico y mapeo basado en el género de la alfabetización genética de estudiantes de secundaria: un estudio transversal en Indonesia

Nível acadêmico e mapeamento baseado em gênero da alfabetização genética de alunos do ensino médio: um estudo transversal na Indonésia

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Abstract

[Objective] Genetic literacy relates to knowledge and skills in utilizing genetic principles for solving various problems or issues related to genetics. Genetic literacy is an essential ability for students to master, as it is related to various current issues, especially in the fields of health and agriculture. However, research on genetic literacy has not been properly developed from different perspectives, including those related to academic level and gender. Therefore, to fill this gap, the present research seeks to measure the genetic literacy of Indonesian high school students in relation to their academic level and gender. **[Methodology]** Data were collected using an analytic observational cross-sectional study. The research participants were 1102 students from 55 senior high schools in Indonesia. The participants took a test, which had been evaluated for validity and reliability. The data was then analyzed using ANOVA, and the participants' genetic literacy levels were categorized as adequate or inadequate. **[Results]**. The study showed that students' genetic literacy was relatively inadequate. While academic level was significantly related to students' genetic literacy, gender was not. **[Conclusions]** The results of this study indicate that the academic level has a significant effect on the level of students' genetic literacy, while gender does not. The findings support the conclusion that genetic literacy needs to be considered in education, and that it is necessary that teachers and schools design appropriate strategies to empower and increase students' genetic literacy in high school settings.

Keywords: academic level; gender; genetic literacy; high school students.

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Resumen

[**Objetivo**] La alfabetización genética se relaciona con el conocimiento y las habilidades que permiten utilizar los principios genéticos para resolver diversos problemas o asuntos relacionados con la genética. Es una habilidad imprescindible que los estudiantes deben dominar, ya que está relacionada con diversos temas de actualidad, especialmente en los campos de la salud y la agricultura. Sin embargo, no ha sido investigada apropiadamente desde diferentes puntos de vista, incluidos el nivel académico y el género. Por lo tanto, para llenar este vacío, la presente investigación tiene como objetivo medir la alfabetización genética de los alumnos de secundaria de Indonesia, en asocie con su nivel académico y género. [**Metodología**] Los datos fueron recolectados mediante un estudio observacional analítico transversal. Los participantes del estudio fueron 1102 estudiantes de 55 centros de enseñanza de secundaria de Indonesia. Ellos realizaron una prueba cuya validez y confiabilidad fueron evaluadas. Luego, la información se analizó mediante ANOVA y los niveles de alfabetización genética de los involucrados se clasificaron como adecuados o inadecuados. [**Resultados**]. El trabajo mostró que la alfabetización genética de quienes se seleccionó era relativamente inadecuada. Si bien el nivel académico mostró una relación significativa con la alfabetización genética de los estudiantes, el género no. [**Conclusiones**] Los resultados de esta pesquisa indican que el nivel académico tiene un efecto significativo en el de alfabetización genética estudiantil, mientras que el género no. Los hallazgos respaldan la conclusión de que la alfabetización genética debe considerarse en la educación y que tanto los maestros como los centros educativos deben diseñar estrategias apropiadas para empoderar y aumentar dicha alfabetización de los alumnos en el entorno de la educación secundaria.

Palabras clave: nivel académico; género; alfabetización genética; estudiantes de secundaria.

Resumo

[Objetivo] A alfabetização genética refere-se ao conhecimento e às habilidades que permitem que os princípios genéticos sejam usados para resolver vários problemas ou questões relacionadas à genética. A alfabetização genética é uma competência essencial que os alunos devem dominar, pois está relacionada com diversos temas atuais, especialmente nas áreas da saúde e da agricultura. No entanto, a alfabetização genética não foi adequadamente investigada a partir de diferentes perspectivas, incluindo o nível acadêmico e o gênero. Portanto, para preencher esta lacuna, a presente pesquisa visa medir a alfabetização genética de estudantes indonésios do ensino médio em relação ao seu nível acadêmico e gênero. **[Metodologia]** Os dados foram coletados por meio de estudo observacional analítico transversal. Os participantes da pesquisa foram 1.102 alunos de 55 escolas do ensino médio da Indonésia. Os participantes realizaram um teste cuja validade e confiabilidade foram avaliadas. Os dados foram então analisados por meio de ANOVA e os níveis de alfabetização genética dos participantes foram classificados como adequados ou inadequados. **[Resultados]** O estudo mostrou que a alfabetização genética dos alunos era relativamente inadequada. Embora o nível acadêmico tenha mostrado uma relação significativa com a alfabetização genética dos alunos, o gênero não o fez. **[Conclusões]** Os resultados deste estudo indicam que o nível acadêmico tem um efeito significativo no nível de alfabetização genética dos alunos, enquanto o gênero não. Os resultados apoiam a conclusão de que a alfabetização genética deve ser considerada na educação e que os professores e as escolas devem conceber estratégias adequadas para capacitar e aumentar a alfabetização genética dos alunos no ensino médio.

Palavras-chave: nível acadêmico; gênero; alfabetização genética; estudantes do ensino médio.

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Introduction

Generally, almost all aspects of life have been influenced by genetic developments (Bernardo, 2020; Dumache & Enache, 2016; John & Anaya, 2015; Machová & Ehler, 2023). Genetics is a topic that is often intertwined with many other life sciences so its knowledge is very important for life (Adelana *et al*., 2023). For example, genetics can be intertwined with the fields of health and forensic science as well as agriculture and technology (Boerwinkel *et al*., 2017; Machová & Ehler, 2023). A good and in-depth understanding of genetic concepts will have an impact on all aspects of life. The application of content in gene technology is increasingly expanding into the public sphere, increasing the importance of paying attention to genetic issues (Kampourakis *et al*., 2014).

In-depth knowledge of the modern genetic content of the genome and its properties, such as genetic technology and genetic discrimination, is necessary to respond to genetic problems (Stern & Kampourakis, 2017). For example, many advertising media spread hoax news related to genetic engineering, including the issue of the use of genetically engineered food and skin care products and the COVID-19 case (Chapman *et al*., 2019; Gonzalez *et al*., 2020). Exposure to genetic information in society brings about the need for individuals to counter the spread of hoax news on social media, such as on Twitter (Krittanawong *et al*., 2020), Facebook (Ahmed *et al*., 2020), and WhatsApp (Bowles *et al*., 2020). Furthermore, increasing understanding of genetics can encourage increased knowledge of genetics and prevent students from misconceptions (Cebesoy & Öztekin, 2016; Etobro & Banjoko, 2017; Kantahan *et al*., 2020). Therefore, it is important to empower and increase students' genetic literacy to the maximum (Cebesoy & Öztekin, 2016).

Genetic literacy is part of scientific literacy (Boerwinkel *et al*., 2017). Scientific literacy is not only limited to mastering scientific knowledge and attitudes but also realizing when and how they should be able to use them. Genetic literacy is related to a person's ability to use scientific thinking related to genetics (Chapman *et al*., 2017). Genetic literacy can direct someone to make the right decisions regarding discussions of genetic applications and technology (Cebesoy & Oztekin, 2018). Furthermore, genetic literacy relates to knowledge of genetic principles and individual competence to understand, use, correlate, assess, and apply genetic information to argue, reason, and decide genetic problems in maintaining or improving the quality of personal and social well-being (Maghfiroh *et al*., 2023).

Genetic literacy is also conceptualized as a set of knowledge, skills, or relationships (Maghfiroh *et al*., 2023). Genetic literacy is generally defined as an individual's ability to use genetic knowledge consisting of the nature of genetic material, transmission, gene expression, gene regulation, evolution, and genetics and society. A concept needs to be reduced and added due to variations in views to obtain a concept of genetics that is relevant for citizens in the twenty-first century. For example, Boerwinkel *et al*., (2017) argue that genetic literacy excludes evolution and natural selection. Thus, the core concepts in genetic literacy consist of the nature of genetic material, genetic transmission, genetic expression, and genetic regulation (Aivelo & Uitto, 2021; Boerwinkel *et al*., 2017; Fauzi *et al*., 2022).

Skills in genetic literacy also have a significant role in shaping an individual's

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way of thinking in obtaining and using information related to genetic problems (Erduran *et al*., 2019; Fang *et al*., 2019; Sadler & Donnelly, 2006; Shea *et al*., 2015). There are doubts about the usefulness of information and knowledge because highly knowledgeable people may not be able to apply the acquired genetic knowledge, which has resulted in some researchers recommending additional skills in genetic literacy (Aivelo & Uitto, 2021; Fauzi *et al*., 2022; Shea *et al*., 2015).

During the COVID-19 pandemic in Indonesia, the abundance of gene information means that someone needs to ward off hoax news on social media (Liday & Liwag, 2021). Therefore, Individuals need situational skill features to evaluate the truth of claims about genetic issues and make decisions (Fauzi *et al*., 2022). Based on its needs, genetic literacy skills consist of two main components: argumentation skills and decision-making skills. Argumentation skills are used to support knowledge claims by presenting evidence and logical reasoning. On the other hand, decision-making skills involve the use of various reasoning strategies, including intuitive and analytical approaches, especially in practical applications (Wimmer *et al*., 2022).

Based on the definition of genetic literacy previously explained, genetic literacy can be interpreted as a set of knowledge related to genetic principles and skills in utilizing these principles to solve various problems related to genetic issues. As one of the core concepts in biology, understanding genetics is very important for understanding biology itself, and even understanding the concept of genetics is an important aspect of scientific literacy so it is important to learn (Cary & Branchaw, 2017). Apart from that, genetics is also a popular topic and has an important role in the world of human health and should be well understood by every student (Ricciardi & Stefania, 2017). This provides an opportunity for schools to provide learning that can make students understand the concept of genetics well (Kılıç & Sağlam, 2014; Mohammed *et al*., 2022).

In Indonesia, genetics is taught as part of formal education and is included in the science curriculum regulated by the Indonesian government. Our study of the Indonesian science curriculum, especially the concept of genetics for elementary schools, middle schools, and high schools, is based on data accessed from the official website of the Indonesian Ministry of Education and Culture (http://kronik.kemdikbud.go.id/), Which refers to the Indonesian curriculum which is still used today, called the 2013 curriculum. Based on this curriculum, Students start studying genetics at the elementary school level. At this level, students learn genetics which is still very basic, namely related to the concept of self-recognition. In this concept, students are taught to be able to recognize themselves by comparing themselves with their father or mother, for example by looking at differences in skin color and the shape of their hair. This concept is part of the concept of inheritance in genetics (Juniati & Subali, 2017). Next, students return to studying genetics in the last class at the junior high school level, namely class IX. Class IX students learn about genetic material, such as DNA and RNA, and biological inheritance (Rusmana *et al*., 2021). After that, genetics was taught in high school and vocational school curricula. At the high school level, genetics is taught to class XII students in the science pathway (Rusmana *et al*., 2021). The material studied by upper secondary school students is more complex genetic material, such as genetic

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variation and manipulation. Apart from that, class XII students are also directed to be able to create solutions to problems based on local, national, or global issues related to understanding genetics and inheritance. Furthermore, genetics in vocational schools is only taught to students enrolled in certain pathways such as nursing, and pharmacy. A good understanding of genetic concepts in high school will help students to understand more complex genetic concepts when they enter the college environment.

However, there are many problems when genetics is taught in schools. Some problems that often arise include students having difficulty synthesizing knowledge into deeper understanding (Machová & Ehler, 2023), many students are afraid of genetics (Chattopadhyay, 2005; Paul, 2018), and a high level of misunderstanding about genetics (Vlčková *et al*., 2016). Students consider genetics material to be too theoretical and not contextual enough (Cebesoy & Tekkaya, 2012; Osman *et al*., 2017). The broad scope of the material, the large number of terms used, and abstract concepts make it difficult for students to remember important concepts in genetics material so understanding and mastery of concepts is relatively weak. (Adelana *et al*., 2023; Altunoğlu & Şeker, 2015; Cebesoy & Oztekin, 2018; Kılıç & Sağlam, 2014). Abstract concepts in genetic material can influence students' understanding (Kantahan et al., 2020).

Students' ability to understand a concept is also thought to be influenced by several factors, one of which is academic level (Özcan, 2021; Shi & Qu, 2022; Yu, 2021). Academic level relates to the level of student development and the level of complexity of the material provided by teachers to students (Yu, 2021). Furthermore, Academic level is also related to age level (Gericke *et al*., 2017). Age can influence genetic literacy because as you get older, factual and conceptual knowledge about genetics will increase (Fitzgerald-Butt *et al*., 2016; Gericke *et al*., 2017). This increase in genetic literacy is obtained from a person's experience gained from the level of education they have taken. At the high school level, the material obtained by students becomes more complex, so eventually differences in academic level have the potential to influence student literacy (Delic, 2020).

Furthermore, various efforts are made to help students be able to concretize abstract material on the concept of genetics. For example, these efforts include teaching students to use various strategies. However, in implementation, the ability of male and female students to absorb and understand material may be different (Heo & Toomey, 2020; Liew *et al*., 2022). Students' ability to absorb and understand the material is different between men and women (Aytekin & Isiksal-Bostan, 2019). Students' ability to absorb and master the material well will support their genetic literacy (Mohammed *et al*., 2022). Therefore, gender is also thought to be a factor that influences students' genetic literacy. Gender includes a person's identity, role, personality, and behavior that influence interactions between one individual and another individual, decision-making, and responses given to certain conditions. (Oertelt-Prigione & Mariman, 2020).

The studies indicated that men and women have differences in the biological structure of the brain which causes their cognition and behavior to be different, including learning behavior. (Szadvári *et al*., 2023). Previous research also showed that from a biological perspective, scientists found that there are genes related to the development of vocalization, language,

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including writing that are more active in girls than in boys. They found that in girls, this gene produces more protein than in boys. This may explain why in the first years of life girls learn language earlier and faster than boys (Oertelt-Prigione & Mariman, 2020). Therefore, generally, women are better at speaking and writing. This statement is supported by research results Al-Saadi (2020), which shows that female students outperform males in terms of writing fluency, text quality, and reading. Women also have a mindset that is focused on things that are emotional, concrete, personal, and practical. Meanwhile, men generally have better numeracy skills and an intellectual, rational, and objective mindset (Yu, 2021). It was further explained that female students understand more easily and can think critically, organize their thoughts, and process information than male students. (Saleh *et al*., 2023). However, decision-making skills do not show differences between men and women (McKnight *et al*., 2021).

Gender-based research has been widely conducted to assess gaps in students' cognitive abilities. For example, research conducted by Cebesoy and Oztekin (2016) exploring the spatial intelligence gap revealed that male and female students demonstrated high levels of intelligence in exam scenarios. However, although investigations have delved into areas such as spatial intelligence, the discourse around genetic literacy remains relatively uncharted in terms of explaining potential gender-related differences in abilities. This gap underscores the need for further exploration of gender dynamics that may influence genetic literacy.

Based on this explanation, genetic literacy is thought to be influenced by several factors. Analysis of factors related to genetic literacy needs to be carried out because the information is still very limited (Chapman *et al*., 2019). Furthermore, research that focuses on the relationship between gender factors and the academic level of genetic literacy is also still limited. Research by Swandayani et al. (2021) was conducted to measure the impact of several factors, for example, department specifications on genetic literacy. Meanwhile, other research examines the impact of sex in genomic research (Oertelt-Prigione & Mariman, 2020) and the impact of age on genetic literacy (Fitzgerald-Butt *et al*., 2016; Gericke *et al*., 2017). However, these studies have not focused on examining gender and academic level factors with genetic literacy, so this research is important to carry out. Therefore, this research aims to map students' genetic literacy and investigate the relationship between academic level and gender and literacy genetics of high school students. Mapping genetic literacy and factors that may be related, namely class level and gender is important to study because it can be a basis for consideration for teachers and schools to determine what steps can be taken next to increase students' genetic literacy.

Methodology

Research Design

The present study employed an analytic observation with a cross-sectional study design (Creswell, 2012). This cross-sectional study design was used to measure the level of genetic literacy of high school students in Indonesia and its relationship with class level and gender. This cross-sectional design was chosen because it is a type of quantitative, non-experimental research design that is commonly used

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to collect data from a group of subjects at only one point in time. (Schmidt & Brown, 2019). The cross-sectional design is generally recognized as an efficient and economical method. This method is well suited for hypothesis formulation and provides information on the prevalence of outcomes and exposures, which can provide a basis for other study designs (Wang & Cheng, 2020). Cross-sectional designs are often used to determine the relationship between demographic factors (eg academic level and gender) and literacy (Liu *et al*., 2023; Moshki *et al*., 2018; Nair *et al*., 2022; Özdemir *et al*., 2023; Protheroe *et al*., 2016).

Participants

The sampling process began by distributing informed consent forms to students in 55 high schools in the Western, Central, and Eastern regions of Indonesia. We send forms to students through teachers from their respective schools. A total of 1200 students responded to the form. Next, students need to provide a statement "agree or not" to participate in the research. Thus, students who agree to participate in this research can immediately begin the test distributed through an online survey after completing their personal information.

A total of 1122 out of 1200 students have expressed their consent to participate in this research. However, 15 students were indicated to come from junior high school and 5 students came from the social department, so these data were excluded. Therefore, the remaining 1102 students were participants in this study. The participants were students at the high school level in Indonesia. They are spread across three academic levels, namely classes X, XI, and XII, and are registered in the even semester of the 2022/2023 academic year. Data shows that the response rate was 91.83%. Table 1 presents participant characteristics.

Research Instruments and Data Collection

Instrument design and data collection were carried out for five months, starting from September 2022 to January 2023. Before carrying out the research, letters of approval were sent to educational institutions in several regions of Indonesia, requesting permission to survey high school students. After obtaining approval, coordination is carried out with teachers in each school to support the distribution process of the tests to be used.

The instrument used is a genetic literacy test question consisting of 30 items which were developed concerning dimensions and indicators of genetic literacy according to (Boerwinkel *et al*., 2017 and Bowling et al.,

Table 1. *Characteristics of the Participants*

Academic level	Gender	Amount	%	Total and Percentage (%)	
				Academic Level	Gender
X	Male	48	4.36	127 (11.52)	Male
	Female	79	7.17		
XI	Male	37	3.36	147 (13.34)	343 (31.12)
	Female	110	9.98		Female
XII	Male	258	23.41	828 (75.14)	759 (68.88)
	Female	570	51.72		

Note: derived from research.

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2008). The question items were translated into Indonesian and then modified by the researchers to suit the needs of this research. The modified genetic literacy instrument includes knowledge and skills dimensions. The knowledge dimension consists of the nature of the genetic material (eight questions), gene transmission (four questions), gene regulation (four questions), gene expression (six questions), and the skills dimension, while the skills dimension consists of argumentation (four questions), and decision making skills (four questions).

The instrument that has been translated and modified was then tested for validity and reliability. Validity testing includes content and construct validation (empirical). Content validation tests were carried out to evaluate the extent to which the instrument questions were supported by a theoretical basis. This process involves two geneticists whose task is to assess the suitability of the material content. The geneticist provided input regarding the suitability of the genetic content presented in the instrument with aspects of the genetic literacy dimensions. Apart from that, geneticists also provide suggestions regarding some of the content in each question so that it is in accordance with the supporting theoretical basis. Examples of questions for each dimension in the modified and validated genetic literacy instrument are presented sequentially in Table 2.

After that, a construct validity test was carried out, where the question items were checked by an experienced biology teacher to evaluate the suitability of the question items. The teacher provides input regarding

Table 2. *Examples of questions for each dimension of genetic literacy*

Knowledge Dimensions:
Nature of the Genetic Material (Question Number 13)
The relationship between DNA and chromosomes in higher organisms is...
A. Chromosomes are found in DNA.
B. DNA is found in chromosomes.
C. There is no difference between DNA and chromosomes.
D. DNA and chromosomes are completely separate structures.
E. Chromosomes produce DNA.
Gene Transmission (Question Number 6)
Sometimes a trait seems to disappear in a family and then reappears in the next generation. If neither parent has the trait, but some of the offspring do, then what you will conclude about the inheritance of the trait is...
A. Both parents are carriers of the recessive gene.
B. Only one parent has two breaks in the recessive gene.
C. Only one of the parents has the dominant form of the gene.
D. Only one parent has the recessive gene.
E. It is most likely the result of a new mutation in each parent.
Gene Regulation (Question Number 14)
Regarding complex traits such as IQ, lung cancer, prostate cancer, etc., here is what geneticists describe regarding the contribution of a person's genetic makeup and the environment: …
A. The environment determines the potential of a trait; how much that potential is realized depends on the individual's genetic makeup.
B. Each person increases genetic potential; how much potential can be realized depends on the environment.
C. Geneticists usually accept that most traits are largely determined by genetics with environment having little influence on complex traits.
D. Environment plays a major role in determining complex traits, with genetics playing a relatively minor role.
E. Genetic differences among humans are so small that essentially all of the variation observed among individuals is due to the environment in which they were raised.
Gene Expression (Question Number 10)
A woman is told that she carries a mutation linked to breast cancer. The following statements that show how this affects her chances of getting breast cancer are... …
A. The risk will not be different from that of other healthy women.
B. She is unlikely to get breast cancer.
C. She is at increased risk of breast cancer.
D. She will get breast cancer.

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Skill Dimensions:
Argumentation (Question Number 24) Based on 2020 Global Cancer Observatory (Globocan) data, cervical cancer is in the second most frequently diagnosed position in women. This disease is caused by several factors, for example viral infections, smoking, consumption of highly carcinogenic foods, or various other mutagenic substances that cause mutations in the DICER1 gene, resulting in disruption of the cell division process. Cells will divide uncontrollably and continuously. Based on this information, the most appropriate statement to explain the basic process of cancer is: … A. Carcinogenic substances stimulate cell mutations so that the process of cell multiplication increases. B. Carcinogenic substances stimulate tissue mutations so that the cell multiplication process decreases. C. Mutagenic substances cause DNA recombination so that cell proliferation is disrupted. D. Carcinogenic substances cause gene mutations so that cell proliferation becomes uncontrolled. E. Carcinogenic substances cause DNA recombination so that cell division is disrupted.
Decision-Making Skill (Question Number 30) A woman X is diagnosed with late-stage cervical cancer. The results of the examination showed that the cancer cells showed significant and uncontrolled division, thereby stimulating the formation of tumors and spreading to several surrounding tissues. Based on this information, the best thing that can be done to stop the spread of cancer cells in this patient is … A. Surgery to remove cancer cells so that they can stop their spread. B. Giving drugs to stimulate the immune system so that the spread of cancer cells can be reduced. C. Chemotherapy to stop the spread of cancer cells. D. Radiotherapy to inhibit the spread of cancer cells. E. Gene therapy uses stem cells to reduce the spread of cells.

Note: derived from research.

the relevance of the question items to students' level of understanding and indicators of genetic literacy. Apart from that, the teacher provides input regarding the structure of each question item. Based on this input, the question items were reconstructed to reach an agreement and meet the required content specifications while paying attention to readability. The test was carried out by testing questions on a total of 40 high school students. Data from the validation test shows that the items are valid with a Pearson correlation value and a p-value <0.05.

Next, an empirical reliability test was carried out, and a Cronbach's Alpha reliability coefficient value of 0.94 was obtained. Furthermore, the Cronbach's Alpha reliability coefficient for each dimension of genetic literacy is described as follows: nature of the genetic material (p = 0.78), transmission (p = 0.71), gene regulation (p = 0.69), gene expression (p = 0.77), argumentation (p = 0.67), and decision-making skills (p = 0.70). Based on Cronbach's Alpha value, the reliability of the 30 question items is categorized as very high. The results of construct validity and reliability tests on genetic literacy questions show that these questions can be relied on to measure students' genetic literacy. The complete results of the reliability analysis are presented in Table 3.

Table 3. *Reliability Test Results using Cronbach's Alpha*

Dimensions and Indicators of Genetic Literacy	Cronbach's Alpha Sig.
Nature of the genetic material	0.78
Gene Transmission	0.71
Gene regulation	0.69
Gene expression	0.77
Argumentation	0.67
Decision-making skills	0.70

Note: derived from research.

After the instrument was proven to be valid and reliable, it was prepared and ready to be distributed to the respondents via an online survey. The survey link that was created was then distributed to Biology subject teachers in each school in their respective regions via the WhatsApp (WA) messaging application. WA was chosen because it was considered the most practical method for distributing test instruments. The students

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who were respondents were given the freedom to choose whether they wanted to take the test or not, as an act of ethical consideration. The confidentiality of data submitted by students is also guaranteed and maintained as best as possible. The distribution process involves coordinating with Biology teachers at these schools to ensure test instruments can be easily accessed by students. In this case, WA is used as an efficient and reliable communication channel to disseminate information and overcome logistical obstacles that may arise.

The link that has been obtained contains questions that must be answered by students related to genetic literacy. Students complete these questions in class using their respective mobile devices. The device also helps them to obtain relevant information from outside.

Data Analysis

Before analysis, the data obtained will be checked and sorted first. If there are two or more identical identities, for example, there is more than one identical identity, then the data will not be used. Participant data is also not used if students come from other than high school or non-science levels, for example, there is data from junior high school or social studies. This could happen if the survey link is accidentally distributed by teachers who teach at several schools and levels. The level of genetic literacy used two-term categories: adequate (>50%) and inadequate (≤50%) (Rodriguez *et al*., 2015). Data were analyzed using descriptive and inferential analysis with the help of SPSS. Descriptive analysis describes the genetic literacy value for each dimension and genetic literacy data based on academic level and gender. Descriptive Analysis also describes the dimensions and question number (representing each dimension) on the genetic literacy instrument that most students answered correctly. Furthermore, inferential analysis was carried out using the ANOVA test to determine mean differences between groups (gender and academic level) and their relationship to students' genetic literacy.

Results

Description of Dimensions and Genetic Literacy Questions

This study shows the percentage of participants' responses to a set of assessment indicators derived from dimensions of genetic literacy, which explicitly focus on material or issues that middle school students typically find most challenging. The findings show data on the proportion of students who gave correct answers to each question representing each indicator in the genetic literacy dimension. As seen in Table 4, the average percentage of students with correct answers on the knowledge dimension content indicator "gene expression" is 27.97%. This content indicator has the lowest percentage among all content indicators, both in the knowledge dimension and the skills dimension. The results of the data analysis show that students have a low understanding of the number of genes, gene disorders, gene-protein relationships, and their interactions with the environment in influencing phenotypes which are covered in the topic of gene expression. The percentage that is not much different can be seen from students who answered correctly the question about "gene regulation", namely 33.30%, which shows that students have quite low knowledge about genetic variation in relation to disease, gene regulation, and genetic variation in relation to natural selection.

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Table 4. *The Average Percentages of Students with Correct Answers based on The Dimension and Indicator of Genetic literacy*

Dimensions and Indicators of Genetic Literacy (Question Number)	Average of % Students with Correct Answers
Dimension: Genetic Knowledge	
*Nature of the genetic material (1,4,7,8,11,12,13,18)**	38.68 (426)**
*Gene Transmission (5,6,21,22)**	38.59 (425)**
*Gene regulation (9,10,15,16)**	33.30 (367)**
*Gene expression (2,3,14,17,19,20)**	27.97 (308)**
Dimensions: Genetic Skills	
*Argumentation (24,26,27,28)**	30.89 (340)**
*Decision-making skills (23,25,29,30)**	32.65 (360)**

Note: * is *question number for each dimensions of genetic literacy; ()** is the number of students who answered correctly*
Note: derived from research.

Furthermore, students seemed to have sufficient knowledge about "gene transmission". As many as 38.59% of students answered correctly the questions in this knowledge dimension content indicator. These data imply that students have sufficient knowledge of concepts related to Mendelian inheritance patterns and meiosis. Next, 38.68% of students were also found to be quite knowledgeable about the nature of DNA, DNA-gene and chromosome interactions, gene activity and genetic variation as reflected in the content dimension of knowledge "nature of genetic material".

The skills dimension also shows results that are not much different from the knowledge dimension. Students showed "argumentation" skills in the inadequate category, namely 30.89%. The "decision-making skill" skill also shows the inadequate category, namely 32.65%. These data show that students have low skills related to genetics.

A comprehensive description of the dimensions of the material in genetic literacy, which often get wrong responses from students, as well as the question numbers that represent each dimension, are discussed in detail in this research. Based on Figure 1, it can be noted that the dimension of genetic literacy that has the lowest percentage of correct answers, referring to the number of students who provide correct responses, is the dimension of knowledge related to "gene expression" material at 14.7%. Question number 3 was chosen as a representation of the dimensions of knowledge and material. This data reveals that the question related to the material "gene expression" in number 3 is the problem most often answered incorrectly by students, reaching 85.3%. The results of this research indicate that the topic "gene expression" is one aspect of genetics studies that is considered difficult by students. On the other hand, the dimension that often gets correct responses from students, as can be seen from the question number, is the knowledge dimension "nature of genetic material" in question number 1 at 54.4%. Apart from that, the knowledge dimension "gene transmission" in question number 21 of 55.3% is also included in the dimensions and questions that are often answered correctly. Question number 21 is related to the topic of inheritance patterns and Mendel's principles.

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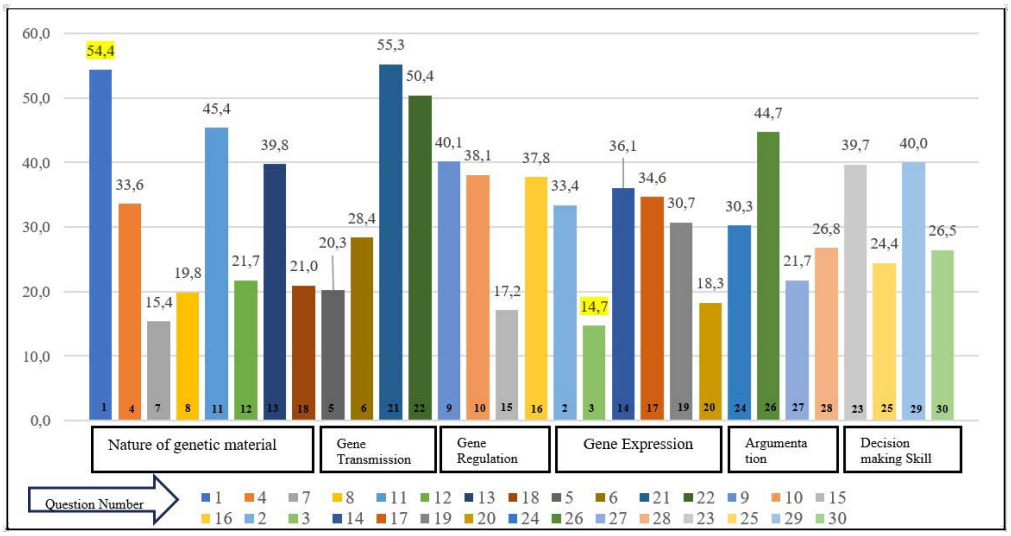

Figure 1. *The percentage of students who gave correct answers to each question number based on the dimensions of genetic literacy.* derived from research.

Table 5. *Average Value of Students' Genetic Literacy Based on Academic Level*

Academic Level	Mean	Amount	Total Genetic Literacy Level (%)*	
			Adequate	Inadequate
X	28.35	127	15 (11.81)	112 (88.19)
XI	28.12	147	21 (14.29)	126 (85.71)
XII	37.27	828	174 (21.01)	654 (78.99)

Note: * *shows the number of students and their percentage (%)*
Note: derived from research.

Table 6. *The Summary of Anova Test on the Effect of Academic Level on the Students' Genetic Literacy*

Source	Type Sum of Squares	df	Mean Square	F	Sig.
Academic level	6436.314	2	3218.157	15.563	0.000*
Error	226636.012	1096	206.785		
Total	1497335.341	1102			

Note: * *Sig value. $p < 0.05$*
Note: derived from research.

Students' Genetic Literacy Based on Academic Level

Findings suggest that differences in academic level cause differences in students' genetic literacy scores. The highest mean genetic literacy score was obtained by class XII students (37.27). The lowest mean came from class XI students, namely 28.12. Meanwhile, the percentage of class XII students who fall into the adequate category (21.01%) is higher than class XI (14.29%) and X (11.81%). Descriptively, the research results indicate that the genetic literacy of class XII students is better than others. A complete description is presented in Table 5. Inferential analysis shows the p-value = 0.000, which means that differences in academic level also determine differences in genetic literacy scores. The complete analysis results are presented in Table 6.

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Analysis results using ANOVA test show that academic level is related to students' genetic literacy scores, so it is necessary to carry out further post hoc tests (LSD). The results of the analysis in Table 7 show that the average genetic literacy of class XI students is the lowest but not significantly different from class X students. The genetic literacy of class.

Students' Genetic Literacy Based on Gender

The genetic literacy analyzed in this study considers differences between male and female students. The research results show that both male and female students generally have genetic literacy that is classified as inadequate. On the other hand, the data also reveals that the percentage of female students who have adequate genetic literacy reached 21.74%, while the percentage of male students was 13.12%. In the descriptive analysis, it is shown that the genetic literacy of female students tends to be higher than that of male students (Table 8). Furthermore, through inferential analysis, it can be concluded that gender is not a determining factor in students' genetic literacy. Details of the analysis can be found in Table 9.

Discussion

In general, the findings of this study reveal that the genetic literacy of high school students in Indonesia can be categorized as inadequate. These results indicate that students' knowledge and understanding of genetic concepts is still at a low level. This data also implies that the genetic literacy of students in Indonesia requires more serious attention and strengthening.

Table 7. *LSD Test Result of the Effect of Academic Level on Students' Genetic Literacy*

Academic level	Corrected Average	SD	LSD notation
X	28.35	10.14	a
XI	28.12	9.75	a
XII	37.27	15.59	b

Note: derived from research.

Table 8. *Average Value of Students' Genetic Literacy Based on Gender*

Gender	Mean	The number of students	Total Genetic Literacy Level (%)*	
			Adequate	Inadequate
Male	30.86	343	45 (13.12)	298 (86.88)
Female	35.04	759	165 (21.74)	594 (78.26)

Note: * *shows the number of students and their percentage (%)*
Note: derived from research.

Table 9. *The Summary of Anova Test on the Effect of Gender on the Students' Genetic Literacy*

Source	Type Sum of Squares	df	Mean Square	F	Sig.
Gender	324.798	1	324.798	1.571	0.210*
Error	226636.012	1096	206.785		
Total	1497335.341	1102			

Note: *Sig value. $p < 0.05$
Note: derived from research.

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The findings are in line with Rujito *et al*. (2020) study which explained that students have a relatively low understanding of genetic concepts and that genetic information presented informally through various types of media is not always correct. For these reasons, it may be difficult for someone without a strong foundation in basic concepts to distinguish valid genetic information from incorrect information (Aivelo & Uitto, 2021). This result can be explained by the fact that the main reason for the low level of student literacy is the shallow treatment of subject content in several dimensions and the main concepts of genetic literacy that are not in-depth, making it impossible for students to learn and understand the main concepts well, coupled with the lack of activities classes and books containing genetic literacy in the library (Mohammed *et al*., 2022). Genetic literacy is part of general scientific literacy, and this type of individual literacy needs to be taken into account, especially because genetics is the basis for studying biology as a whole (Mohammed *et al*., 2022; Samerski, 2014).

Even though it is positioned as a branch of biology that underlies various other branches, genetics is one of the materials that are most difficult for students to understand, both high school students and university students (Etobro & Banjoko, 2017; Kılıç & Sağlam, 2014; Machová & Ehler, 2023; Paul, 2018). Genetics is also a biological concept that is more frequently misunderstood compared to other biological concepts (Gusmalini *et al*., 2020; Kılıç & Sağlam, 2014). Furthermore, students with good mastery of genetics will easily understand various other biological concepts (Nurse & Hayles, 2019). This is because various biological concepts such as cell division and immune response are closely related to genetics. Therefore, measuring genetic literacy is an important effort to measure how strong students' mastery of biology concepts is and to measure the quality of the biology education curriculum in an educational institution (Rujito *et al*., 2020).

Dimensions and Most Difficult Questions

The findings show that the material content in the knowledge dimension "gene expression" is one of the materials in genetics that is considered the most difficult by students. On the other hand, the material most often answered correctly by students is the material "nature of genetic materials" which is represented by question number 1, and the material related to "gene transmission" which is represented by question number 21, which is related to patterns of inheritance and Mendelian traits. These two study materials are considered relatively easier for students to understand compared to other study materials (Machová & Ehler, 2023; Rujito *et al*., 2020).

The findings of this study are in line with Osman *et al*. (2017) and Machová & Ehler's (2023) research suggesting that studying material related to gene expression was a study that was difficult for students to understand. albeit the findings echoed Haskel-Ittah *et al*. (2020) study, the idea of interactions between genes and the environment in the formation of traits is an important component of genetic literature because it explains the plastic nature of the phenotype. Understanding that phenotypes are the developmental result of interactions between genes and the environment is not only important for scientists and scientific investigations. It is also important for students' personal and community engagement with genetics issues (Boerwinkel *et*

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al., 2017). However, most studies in genetics education characterize challenges in understanding and reasoning about genetic phenomena, meaning that students have difficulty understanding the material. (Haskel-Ittah *et al*., 2020; Puig *et al*., 2017). Understanding genetic mechanisms will enable students to provide causal explanations for genetic phenomena. This mechanism is difficult to teach and learn (Haskel-Ittah & Yarden, 2018).

In general, the research results show that students have a low understanding of genetics. Low knowledge and understanding of genetic concepts have an impact on low argumentation skills and decision-making skills related to genetics. Furthermore, "argumentation" skills show a smaller percentage compared to "decision-making skills". The results of this analysis show that students have better decision-making skills compared to argumentation skills related to genetic issues. Although in general, these two skills are still low. Students are better able to make decisions than to argue. This shows that students consider arguing related to genetics to be a difficult thing to do, which makes students tend to ignore it (Puig *et al*., 2017). Although the idea is in line with Songsil *et al*'s. (2019) research, scientific argumentation skills are also important for students to express their opinions and solve problems in everyday life. Argumentation and decision-making skills are two things that are interrelated and are the goals of genetic literacy. If students are involved in structured decision-making regarding personally relevant phenomena, they can develop more integrated argumentation skills (Sparks *et al*., 2022).

Furthermore, the complex nature of genetic problems drives the need for students to have decision-making skills about genetic problems (Stern & Kampourakis, 2017). Decision-making skills are one of the important skills in genetic literacy. Students need sufficient knowledge of genetic concepts such as the nature of genetic material, inheritance, gene expression, and regulation to be able to participate in decision-making (Cebesoy & Oztekin, 2018). Students can use analytical techniques to perform logical thinking and decision-making skills related to genetics (Fang *et al*., 2019).

Students' Genetic Literacy Based on Academic Level

Based on the research results, information was obtained that academic level is related to students' genetic literacy. Academic level is one of the determining factors in the genetic literacy scores obtained by students. The research results show that students at a low academic level get lower grades compared to students at a high academic level. The genetic literacy scores of class XII students are higher than the scores of students in classes X and XI.

Academic level is also related to age, where the older a person is, the more knowledge they have in achieving better learning outcomes. Apart from that, the ability to reason and understand a problem is different between upper-class and lower-class students (Delic, 2020). Students in the upper-classes have high curiosity and social habits. This high level of curiosity will influence the way students think and learn. Low-class students have low curiosity and often make social adaptations that affect students' thinking patterns.

Furthermore, the materials and assignments between upper and lower classes are different, where upper-classes are generally given more complex assignments and material while lower classes are not.

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This influences student knowledge (Gericke *et al*., 2017; Yu, 2021). In addition, high-class students can absorb material better than low-class students (Almendingen *et al*., 2021). Higher-grade students gain more knowledge about genetics through education, life experiences, or media exposure which in turn may influence their understanding. The learning experiences that students go through at each grade level are also different. The upper-classes have had learning experiences from the middle and lower classes so the knowledge of students in the upper-class is much different from that of the middle and lower classes (Gericke *et al*., 2017; Kurthen, 2014).

The results of this research also show that upper-class students have better genetic literacy than lower-class students. This is because high-class students, especially class XII, have been taught genetics material with more adequate information so that their knowledge and understanding become better. Meanwhile, class X has better genetic literacy than class XI because class As explained by several experts (Chattopadhyay, 2005; Ezechi, 2021; Kılıç & Sağlam, 2014) students can remember material that is relevant to their lives, for example, genetics.

To support several previous expert statements, it is important to look again at the material and competencies expected in genetics learning at each academic level. Based on research results from Juniati and Subali (2017), information was obtained that aspects of genetics have been taught from class I of elementary school to class XII of high school, but with different material coverage and competencies. In elementary school, genetic material includes an introduction to genetic inheritance (Hott *et al*., 2002). Meanwhile, at the middle and high school levels, genetic material includes understanding and the ability to be creative, for example analyzing the results of cross-breeding or genetic inheritance.

More specifically, Juniati & Subali (2017) and Rusmana *et al*. (2021) explained that genetic material at the elementary school level regarding the introduction of inheritance in humans focuses on the level of competence in remembering (C1) and understanding (C2). At the junior high school level (class IX), the material covers mechanisms of inheritance, cell division, and mutation with competency levels of understanding (C2), applying (C3), and analyzing (C4). At the high school level (classes X, XI, and XII), genetic material becomes more abstract. Some material may be repeated at different levels, although there are connections between them. Significant differences are also seen in the competencies that students are expected to master for each sub-aspect of genetics.

For example, sub-aspects of genetics such as virus reproduction and mutation are taught in class X with a competency level of understanding (C2). Meanwhile, sub-aspects of plant genetics and animal reproduction are taught in class XI with competency levels of understanding (C2) to analyzing (C4). Sub-aspects of genetics such as mechanisms of cell division to mutation and genetic manipulation are taught in class XII with competency levels from analyzing (C4) to creating (C6). With this explanation, it is important to note that the sub-material of genetics is arranged sequentially, starting from simpler concepts to more complex and abstract concepts (Hott *et al*., 2002). The preparation of this complex and abstract material is based on the level of student development at each academic level.

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Students' Genetic Literacy Based on Gender

The study showcases that there is no relationship between gender and students' genetic literacy. Gender, whether male or female, is not a determining factor in the genetic literacy scores obtained by students. This finding is consistent with research by Yu (2021) which indicates that a person's knowledge is not determined by gender. Factors such as individual learning processes, environment, social interactions, and experience have a greater role in shaping a person's knowledge. These results emphasize that learning approaches and efforts to increase genetic literacy must be inclusive, not viewing gender as the main factor in determining students' understanding of genetic concepts. Therefore, gender does not determine knowledge because the knowledge possessed by male and female students is influenced by the learning process experienced by each individual. The results of this research are in line with the research results (Mohammed *et al*., 2022) that there is no difference in genetic literacy due to the interaction of gender and students' academic level.

Previous research by Piraksa *et al*. (2014) and Ganley and Lubienski (2016) show the same results. The two researchers stated that gender did not have a significant difference in scientific thinking abilities and cognitive learning outcomes for students. Furthermore, a person's knowledge is not completely determined by gender (McKnight *et al*., 2021). The ability to think, personality, and make decisions between men and women is more influenced by the environment, experiences that support one's knowledge, social interactions, and education. (Aguillon *et al*., 2020; McKnight *et al*., 2021; Van Der Vleuten *et al*., 2016). The findings of this research are in line with (Szadvári *et al*. (2023), who reported that male and female students do not have significant differences in making decisions about biological problems in life, especially genetics. Another research conducted by Marni *et al* (2020) found that gender did not have a significant difference in critical thinking abilities and student learning outcomes in biology subjects. Gender also does not affect students' decision-making skills (McKnight *et al*., 2021).

However, the results of other studies show things that are different from the results of this study. Bugler *et al*. (2016) explained that female students have a higher level of motivation and better adaptation. Other experts also explained that female students have a more positive attitude towards science lessons compared to male students (Heng & Karpudewan, 2015). Another study looking at students in Singapore supports this interpretation and argues that female students' more positive self-concept and self-confidence are determinants of their achievement compared to male students (Yoo, 2018). This finding is also in line with (Aytekin & Isiksal-Bostan, 2019) who reported that the ability to think, draw conclusions and reason was different between male and female students so learning outcomes were different. Female students have higher attitudes and abilities compared to male students (Al-Balushi *et al*., 2022).

In fact, different findings may also apply to the present study. As understood, gender is a person's identity that differentiates between men and women (Oertelt-Prigione & Mariman, 2020). Men and women are different due to a combination of genetic and hormonal factors. Current research cannot ignore sex differences in brain anatomy, physiology, and neurochemistry. These differences affect life in adulthood and result

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in differences in physical, and psychological characteristics and learning behavior (Reale *et al*., 2021; Szadvári *et al*., 2023; Xin *et al*., 2019).

Further, Tsaousis and Alghamdi (2022) found that female students showed more internal locus of control in academic performance than male students. Interestingly, Wrigley-Asante *et al*. (2023) revealed that female students outperform male students partly because they are more disciplined. Whereas Dubuc *et al*. (2020) concluded that female students placed more importance on pleasing adults and also placed more emphasis on preparing their academic evaluations so that their results were better than male students. However, based on the results of this study, the average genetic literacy score of female students is higher than that of male students, although not significantly. These results are in line with studies that conclude that female students are consistently able to outperform male students in science tests, although it is not significant (Al-Balushi *et al*., 2022; Egara & Mosimege, 2023).

It is important to note that gender does not determine a student's knowledge and understanding of genetics because this ability is actually influenced by the learning process experienced by the student. The research results are in line with the fact that teaching genetics at an early stage often relies on the lecture method. This method can lead to the formation of inaccurate perceptions among students, namely the assumption that genetics is only a central concept that can be memorized easily. The impact is that students' critical thinking abilities are limited, namely only limited to memorization activities (Chattopadhyay, 2005; Fitzgerald-Butt *et al*., 2016; Machová & Ehler, 2023). Therefore, it is important to update genetics teaching methods, introducing more interactive and engaged learning strategies, to enable students to understand genetics concepts in more depth and develop their critical thinking abilities. In this way, genetics learning focuses not only on memorizing information but also on understanding concepts and developing higher thinking skills.

Based on this explanation, teachers must be able to design appropriate learning to overcome these difficulties. Difficulties in studying and understanding genetics can be overcome by using appropriate learning strategies and media (Ezechi, 2021; McKnight *et al*., 2021), remembering that genetics has many abstract concepts that make it difficult for students to understand. To make it easier for students to understand these abstract concepts, teachers can use experiment-based learning or by utilizing media, for example, digital learning media which is able to visualize abstract concepts in genetics. These efforts will be very helpful in studying and understanding complex objects in biology as a whole (Chin *et al*., 2019; Verdes *et al*., 2021; Wu *et al*., 2013). Furthermore, learning strategies that pay attention to variations in learning styles and utilize the potential of individuals from various gender backgrounds can help create an equitable learning environment and support the development of genetic literacy regardless of student gender.

Conclusion

This research provides a detailed description of the genetic literacy mapping of high school students in Indonesia, as well as presents the results of an investigation into the relationship between academic level and gender on genetic literacy. The findings suggest that students' genetic literacy is predominantly

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in the inadequate category. These findings also confirm that academic level is a determining factor in students' genetic literacy, while gender is not a significant determinant of the genetic literacy of high school students in Indonesia. Overall, this research indicates the need to increase the genetic literacy of high school students. The role of schools is crucial in paying attention to and responding to students' genetic literacy needs, taking into account their academic level and gender. Intervention steps need to be taken to help improve students' genetic literacy at the secondary school level.

Despite the interesting findings obtained in this study, several limitations need to be pointed out. First, this research only involved one level of education, namely high school. Future researchers are encouraged to explore similar issues by involving various levels of education from a wider region of Indonesia. Second, this research only focuses on two factors related to genetic literacy, namely academic level and gender. Thus, future research is expected to investigate more various factors such as department, ethnicity, status, and location of the school. Additionally, further research that analyzes the relationship between these other factors and genetic literacy needs to be designed and carried out.

Furthermore, the inadequate category at all academic levels and genders indicates that genetics learning has not been implemented optimally. The use of strategies and learning media as tools to increase students' genetic understanding and literacy has not been maximized. The results of this research further strengthen the fact that genetic literacy needs to be considered. Therefore, it is necessary to design and use teaching materials that are more explicitly integrated with genetic literacy. The application of more innovative and contextual genetics learning is also important to increase students' motivation and literacy in solving genetics-related problems in a scientific context as a form of competency needed in 21st-century learning.

Overall, this research presents a comprehensive mapping of genetic literacy among high school students in Indonesia. These findings highlight the urgency to increase students' understanding of genetic literacy, given the importance of a deep understanding of genetic concepts in the context of modern education. Strategic steps need to be taken to overcome this lack of genetic literacy, including preparing a more effective curriculum, teacher training, and implementing innovative learning methods. Furthermore, teachers and schools need to design strategies and appropriate learning media. Learning can be carried out using active learning strategies or even experiment-based learning. Apart from that, it can also be supported by the use of various interactive media to facilitate the visualization of learning material so that it can increase the learning motivation, understanding, and genetic literacy of high school students. Various It is hoped that these efforts will make a significant contribution to increasing the genetic literacy level of students in Indonesia, which will ultimately help build a solid foundation of knowledge in the field of genetics.

The results of this research can be a valuable source of information for the government in formulating biology education curricula for secondary schools. These findings provide valuable insights for educators and educational institutions to design appropriate and efficient pedagogical approaches in teaching genetics knowledge at the secondary school level, as well as to improve students' genetic literacy.

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Informed Consent

The authors declare that informed consent was obtained from participants. The data is treated as confidential information used exclusively for research purposes and it is not possible to identify participants from the data.

Author Contributions

All the authors declare that the final version of this paper was read and approved. The total contribution percentage for the conceptualization, preparation, and correction of this paper was as follows: D.S. 40 %., S.Z. 30 %., A.G. 15 % and S.R.L. 15 %.

Conflict of Interest

No potential conflict of interest was reported by the authors.

Data availability statement

The data supporting this study is available through the corresponding author **[S.Z]**, upon a reasonable request.

Preprint

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References

Adelana, O., Akinsulure, A., Ajose, M., & Ishola, A. (2023). Perceptions of Genetics Difficulty Among Science Students. *Journal of Science and Mathematics Letters*, *11 (1)*, 51–58. https://doi.org/10.37134/jsml.vol11.1.7.2023

Aguillon, S. M., Siegmund, G.-F., Petipas, R. H., Drake, A. G., Cotner, S., & Ballen, C. J. (2020). Gender Differences in Student Participation in an Active-Learning Classroom. *CBE—Life Sciences Education*, *19*(2), ar12. https://doi.org/10.1187/cbe.19-03-0048

Ahmed, N., Shahbaz, T., Shamim, A., Shafiq Khan, K., Hussain, S. M., & Usman, A. (2020). The COVID-19 Infodemic: A Quantitative Analysis Through Facebook. *Cureus*, *12*(11) https://doi.org/10.7759/cureus.11346

Aivelo, T., & Uitto, A. (2021). Factors Explaining Students' Attitudes towards Learning Genetics and Belief in Genetic Determinism. *International Journal of Science Education*, *43*(9), 1408–1425. https://doi.org/10.1080/09500693.2021.1917789

Al-Balushi, S. M., Mansour, N., Almehrizi, R. S., Ambusaidi, A. K., & Al-Harthy, I. S. (2022). The Association between the Gender Gap in Science Achievement and Students' Perceptions of their own Attitudes and Capabilities. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(11), em2184. https://doi.org/10.29333/ejmste/12559

Almendingen, K., Morseth, M. S., Gjølstad, E., Brevik, A., & Tørris, C. (2021). Student's Experiences with Online Teaching Following COVID-19 Lockdown: A mixed Methods Explorative Study. *Plos One*, *16*(8), e0250378. https://doi.org/10.1371/journal.pone.0250378

Al-Saadi, Z. (2020). Gender Differences in Writing: The Mediating Effect of Language Proficiency and Writing Fluency in Text Quality. *Cogent Education, 7*, 1770923. https://doi.org/10.1080/2331186X.2020.1770923

DOI: http://dx.doi.org/10.15359/ru.38-1.9
E-ISSN: 2215-3470

Altunoğlu, B., & Şeker, M. (2015). The Understandings of Genetics Concepts and Learning Approach of Pre-Service Science Teachers. *Journal of Educational and Social Research*, *5*(1), 61–66. https://doi.org/10.5901/jesr.2015.v5n1s1p61

Aytekin, E., & Isiksal-Bostan, M. (2019). Middle School Students' Attitudes towards the Use of Technology in Mathematics Lessons: Does Gender Make a Difference? *International Journal of Mathematical Education in Science and Technology*, *50*(5), 707–727. https://doi.org/10.1080/0020739X.2018.1535097

Bernardo, R. (2020). Reinventing Quantitative Genetics for Plant Breeding: Something Old, Something New, Something Borrowed, Something Blue. *Heredity*, *125*(6), 375–385. https://doi.org/10.1038/s41437-020-0312-1

Boerwinkel, D. J., Yarden, A., & Waarlo, A. J. (2017). Reaching a Consensus on the Definition of Genetic Literacy that Is Required from a Twenty-First-Century Citizen. *Science and Education*, *26*(10), 1087–1114. https://doi.org/10.1007/s11191-017-9934-y

Bowles, J., Larreguy, H., & Liu, S. (2020). Countering Misinformation via WhatsApp: Preliminary Evidence from the COVID-19 Pandemic in Zimbabwe. *PLOS ONE*, *15*(10), e0240005-. https://doi.org/10.1371/journal.pone.0240005

Bowling, B. V., Acra, E. E., Wang, L., Myers, M. F., Dean, G. E., Markle, G. C., Moskalik, C. L., & Huether, C. A. (2008). Development and Evaluation of a Genetics Literacy Assessment Instrument for undergraduates. *Genetics*, *178*(1), 15–22. https://doi.org/10.1534/genetics.107.079533

Bugler, M., Mcgeown, S., & St Clair-Thompson, H. (2016). An Investigation of Gender and Age Differences in Academic Motivation and Classroom Behaviour in Adolescents. *Educational Psychology*, *36*(7), 1193–1215. https://doi.org/10.1080/01443410.2015.1035697

Cary, T., & Branchaw, J. (2017). Conceptual Elements: A Detailed Framework to Support and Assess Student Learning of Biology Core Concepts. *CBE—Life Sciences Education*, *16*(2), ar24. https://doi.org/10.1187/cbe.16-10-0300

Cebesoy, U. B., & Oztekin, C. (2018). Genetics Literacy: Insights From Science Teachers' Knowledge, Attitude, and Teaching Perceptions. *Int J of Sci and Math Educ*, *16*, 1247–1268. https://doi.org/10.1007/s10763-017-9840-4

Cebesoy, Ü. B., & Tekkaya, C. (2012). Pre-service Science Teachers' Genetic Literacy Level and Attitudes towards Genetics. *Procedia - Social and Behavioral Sciences*, *31*, 56–60. https://doi.org/10.1016/j.sbspro.2011.12.016

Cebesoy, U., & Öztekin, C. (2016). Relationships among Turkish Pre-Service ScienceTeachers' Genetics Literacy Levels and their Attitudes towards Issues in Genetics Literacy. *Journal of Baltic Science Education*, *15*(2), 159–172. https://doi.org/10.33225/jbse/16.15.159

Chapman, R., Likhanov, M., Selita, F., & Zakharov, I., Smith-Wooley, E. & Kovas, Y. (2017). Genetic Literacy And Attitudes Survey (Iglas): International Population-Wide Assessment Instrument. *The European Proceedings of Social & Behavioural Sciences EpSBS*, *33*(6), 45–66. https://doi.org/10.15405/epsbs.2017.12.6

Chapman, R., Likhanov, M., Selita, F., Zakharov, I., Smith-Woolley, E., & Kovas, Y. (2019). New Literacy Challenge for the Twenty-First Century: Genetic Knowledge is Poor even among Well Educated. *Journal of Community Genetics*, *10*(1), 73–84. https://doi.org/10.1007/s12687-018-0363-7

Chattopadhyay, A. (2005). Understanding of Genetic Information in Higher Secondary Students in Northeast India and the Implications for Genetics Education. *Cell Biology Education*, *4*(1), 97–104. https://doi.org/10.1187/cbe.04-06-0042

Chin, K.-Y., Wang, C.-S., & Chen, Y.-L. (2019). Effects of an Augmented Reality-based Mobile System on Students' Learning Achievements and Motivation for a Liberal Arts Course. *Interactive Learning Environments*, *27*(7), 927–941. https://doi.org/10.1080/10494820.2018.1504308

Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research*. Pearson.

Delic, H. (2020). The Analysis of Learning Styles among High School Students. *Journal of Education and Humanities*, *2*(2), 17–28.

Dubuc, M.-M., Aubertin-Leheudre, M., & Karelis, A. D. (2020). Gender Differences in Academic Performance of High School Students: The Relationship with Cardiorespiratory Fitness, Muscle Endurance, and Test Anxiety. *International Journal of Preventive Medicine*, *11:201*, 1–7. https://journals.lww.com/ijom/fulltext/2020/11000/gender_differences_in_academic_performance_of_high.201.aspx

UNICIENCIA Vol. 38, N° 1, pp. 1-26. January-December, 2024 • www.revistas.una.ac.cr/uniciencia • revistauniciencia@una.cr

DOI: http://dx.doi.org/10.15359/ru.38-1.9
E-ISSN: 2215-3470

Dumache, R., Ciocan, V., Muresan, C. & Enache, A. (2016). Molecular Genetics and its Applications in Forensic Sciences. In *In Forensic Analysis -From Death to Justice. InTech.* https://doi.org/10.5772/63530

Egara, F. O., & Mosimege, M. D. (2023). Gender Difference in Secondary School Students' Retention in Algebra: A Computer Simulation Approach. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(7), em2290. https://doi.org/10.29333/ejmste/13280

Erduran, S., Guilfoyle, L., Park, W., Chan, J., & Fancourt, N. (2019). Argumentation and Interdisciplinarity: Reflections from the Oxford Argumentation in Religion and Science Project. *Disciplinary and Interdisciplinary Science Education Research*, *1*(1), 1–10. https://doi.org/10.1186/s43031-019-0006-9

Etobro, A. B., & Banjoko, S. O. (2017). Misconceptions of Genetics Concepts among Pre-Service Teachers. *Global Journal of Educational Research*, *16*(2), 121–128. https://doi.org/10.4314/gjedr.v16i2.6

Ezechi, N. G. (2021). The Problems of Teaching and Learning Genetics in Secondary Schools in Enugu South Local Government Area of Enugu State. *British International Journal of Education and Social Sciences*, *8*(4), 13–19. Retrieved from https://cirdjournal.com/index.php/bijess/article/view/230

Fang, S.-C., Hsu, Y.-S., & Lin, S.-S. (2019). Conceptualizing Socioscientific Decision Making from a Review of Research in Science Education. *International Journal of Science and Mathematics Education*, *17*(3), 427–448. https://doi.org/10.1007/s10763-018-9890-2

Fauzi, A., Saefi, M., Adi, W. C., Kristiana, E., & Lestariani, N. (2022). Instrument evaluation of conspiracy theory about COVID-19: Exploratory factor analysis and confirmatory factor analysis. *International Journal of Evaluation and Research in Education (IJERE)*, *11*(2), 491–498. https://doi.org/10.11591/ijere.v11i2.22339

Fitzgerald-Butt, S. M., Bodine, A., Fry, K. M., Ash, J., Zaidi, A. N., Garg, V., Gerhardt, C. A., & McBride, K. L. (2016). Measuring Genetic Knowledge: A Brief Survey Instrument for Adolescents and Adults. *Clinical Genetics*, *89*(2), 235–243. https://doi.org/10.1111/cge.12618

Ganley, C. M., & Lubienski, S. T. (2016). Mathematics Confidence, Interest, and Performance: Examining Gender Patterns and Reciprocal Relations. *Learning and Individual Differences*, *47*, 182–193. https://doi.org/10.1111/cge.12618

Gericke, N., Carver, R., Castéra, J., Evangelista, N. A. M., Marre, C. C., & El-Hani, C. N. (2017). Exploring Relationships Among Belief in Genetic Determinism, Genetics Knowledge, and Social Factors. *Science and Education*, *26*(10), 1223–1259. https://doi.org/10.1007/s11191-017-9950-y

Gonzalez, T., de la Rubia, M. A., Hincz, K. P., Comas-Lopez, M., Subirats, L., Fort, S., & Sacha, G. M. (2020). Influence of COVID-19 Confinement on Students' Performance in Higher Education. *Plos One*, *15*(10), 1-23: e0239490. https://doi.org/10.1371/journal.pone.0239490

Gusmalini, A., Wulandari, S., & Zulfarina. (2020). Identification of Misconceptions and Causes of Student Misconceptions on Genetics Concept with CRI Method. *Journal of Physics: Conference Series*, *1655*(1), 1-5, 012053. https://doi.org/10.1088/1742-6596/1655/1/012053

Haskel-Ittah, M., & Yarden, A. (2018). Students' Conception of Genetic Phenomena and Its Effect on Their Ability to Understand the Underlying Mechanism. *CBE Life Science Education*, *17*(3), 1-9: ar36. https://doi.org/10.1187/cbe.18-01-0014

Haskel-Ittah, M., Duncan, R. G., & Yarden, A. (2020). Students' Understanding of the Dynamic Nature of Genetics: Characterizing Undergraduates' Explanations for Interaction between Genetics and Environment. *CBE Life Sciences Education*, *19*(3), 1-13: ar37. https://doi.org/10.1187/cbe.19-11-0221

Heng, C. K., & Karpudewan, M. (2015). The Interaction Effects of Gender and Grade Level on Secondary School Students' Attitude towards Learning Chemistry. *Eurasia Journal of Mathematics, Science and Technology Education*, *11*(4), 889–898. https://doi.org/10.12973/eurasia.2015.1446a

Heo, M., & Toomey, N. (2020). Learning with Multimedia: The Effects of Gender, Type of Multimedia Learning Resources, and Spatial Ability. *Computers & Education*, *146*, 103747. https://doi.org/10.1016/j.compedu.2019.103747

DOI: http://dx.doi.org/10.15359/ru.38-1.9
E-ISSN: 2215-3470

Hott, A. M., Huether, C. A., McInerney, J. D., Christianson, C., Fowler, R., Bender, H., Jenkins, J., Wysocki, A., Markle, G., & Karp, R. (2002). Genetics Content in Introductory Biology Courses for Non-Science Majors: Theory and Practice. *BioScience*, *52*(11), 1024–1035. https://doi.org/10.1641/0006-3568(2002)052[1024:GCIIBC]2.0.CO;2

John, C., & Anaya, J.-M. (2015). Genetics and Vaccines in the Era of Personalized Medicine. *Current Genomics*, *16*(1), 47–59. https://doi.org/10.2174/1389202916666141223220551

Juniati, E., & Subali, B. (2017). Teacher's Opinion about Learning Continuum of Genetics Based on Student's Level of Competence. *AIP Conference Proceedings*, *1868*(1), 100002. https://doi.org/10.1063/1.4995212

Kampourakis, K., Reydon, T., Patrinos, G., & Strasser, B. (2014). Genetics and Society-Educating Scientifically Literate Citizens: Introduction to the Thematic Issue. *Science & Education*, *23*, 251–258. https://doi.org/10.1007/s11191-013-9659-5

Kantahan, S., Junpeng, P., Punturat, S., Tang, K. N., Gochyyev, P., & Wilson, M. (2020). Designing and Verifying a Tool for Diagnosing Scientific Misconceptions in Genetics Topic. *International Journal of Evaluation and Research in Education (IJERE)*, *9*(3), 564–571. https://doi.org/10.11591/ijere.v9i3.20544

Kılıç, D., & Sağlam, N. (2014). Students' Understanding of Genetics Concepts: The Effect of Reasoning Ability and Learning Approaches. *Journal of Biological Education*, *48*(2), 63–70. https://doi.org/https://doi.org/10.1080/00219266.2013.837402

Krittanawong, C., Narasimhan, B., Virk, H. U. H., Narasimhan, H., Hahn, J., Wang, Z., & Tang, W. H. W. (2020). Misinformation Dissemination in Twitter in the COVID-19 Era. *The American Journal of Medicine*, *133*(12), 1367–1369. https://doi.org/10.1016/j.amjmed.2020.07.012

Kurthen, H. (2014). What Influences College Classroom Interaction? *International Journal of Assessment and Evaluation*, *20*(4), 13–34. https://doi.org/10.18848/2327-7920/CGP/v20i04/58943

Liday, D., & Liwag, C. (2021). Eating Behavior and Physical Activity of Senior Citizens during the COVID-19 Lockdown. *International Journal of Public Health Science (IJPHS)*, *10*(3), 493–499. https://doi.org/10.11591/ijphs.v10i3.20827

Liew, T. W., Tan, S.-M., Gan, C., & Wei Ming, P. (2022). Colors and Learner's Gender Evoke Different Emotional and Cognitive Effects in Multimedia Learning. *Human Behavior and Emerging Technologies*, *2022*, 1–15. https://doi.org/10.1155/2022/1235732

Liu, Y., Wu, N., Yan, J., Yu, J., Liao, L., & Wang, H. (2023). The Relationship between Health Literacy and Internet Addiction among Middle School Students in Chongqing, China: A Cross-Sectional Survey Study. *Plos One*, *18*(3), 1-18: e0283634. https://doi.org/10.1371/journal.pone.0283634

Machová, M., & Ehler, E. (2023). Secondary School Students' Misconceptions in Genetics: Origins and Solutions. *Journal of Biological Education*, *57*(3), 633–646. https://doi.org/https://doi.org/10.1080/00219266.2021.1933136

Maghfiroh, H., Zubaidah, S., Mahanal, S., & Susanto, H. (2023). Definition and Conceptual Model of Genetics Literacy: A Systematic Literature Review. *International Journal of Public Health Science (IJPHS)*, *12*(2), 554–567. https://doi.org/10.11591/ijphs.v12i2.22679

Marni, S., Aliman, M., Suyono, S., Roekhan, R., & Harsiati, T. (2020). Students' Critical Thinking Skills Based on Gender And Knowledge Group. *Journal of Turkish Science Education, 17*(4), 543–560. https://doi.org/10.36681/tused.2020.44

McKnight, L., Pearce, A., Willis, A., Young, M. A., & Terrill, B. (2021). Supporting Teachers to Use Genomics as a Context in the Classroom: An Evaluation of Learning Resources for High School Biology. *Journal of Community Genetics*, *12*(4), 653–662. https://doi.org/https://doi.org/10.1007/S12687-021-00550-3

Mohammed, A. R., Habeeb, R. R., & Al-Muhja, N. A. H. (2022). Genetic Literacy for Students in Faculties of Education in Universities. *Varidika*, *34*(2), 72–84. https://journals.ums.ac.id/index.php/varidika/article/view/19102

Moshki, M., Mirzania, M., & Kharazmi, A. (2018). The Relationship of Health Literacy to Quality of Life and Demographic Factors in pregnant women: A Cross-Sectional Study. *Journal of Health Literacy*, *2*(4), 203–215.

Nair, S. C., Sreedharan, J., Satish, K. P., & Ibrahim, H. (2022). Health Literacy in a High Income Arab Country: A Nation-Wide Cross-Sectional Survey Study. *PLOS ONE*, *17*(10), 1-11: e0275579. https://doi.org/10.1371/journal.pone.0275579

UNICIENCIA Vol. 38, N° 1, pp. 1-26. January-December, 2024 • www.revistas.una.ac.cr/uniciencia • revistauniciencia@una.cr

DOI: http://dx.doi.org/10.15359/ru.38-1.9
E-ISSN: 2215-3470

Nurse, P., & Hayles, J. (2019). Using genetics to understand biology. *Heredity*, *123*(1), 4–13. https://doi.org/10.1038/s41437-019-0209-z

Oertelt-Prigione, S., & Mariman, E. (2020). The Impact of Sex Differences on Genomic Research. *The International Journal of Biochemistry & Cell Biology*, *124*(2020), 1-10: 105774. https://doi.org/10.1016/j.biocel.2020.105774

Osman, E., Boujaoude, S., & Hamdan, H. (2017). An Investigation of Lebanese G7-12 Students' Misconceptions and Difficulties in Genetics and Their Genetics Literacy. *Int J of Sci and Math Educ*, *15*(7), 1257–1280. https://doi.org/https://doi.org/10.1007/s10763-016-9743-9

Özcan, M. (2021). Factors Affecting Students' Academic Achievement According to the Teachers' Opinion. *Education Reform Journal*, *6*(1), 1–18. https://doi.org/10.22596/erj2021.06.01.1.18

Özdemir, R., Bektemur, G., Keles, E., & Baydili, K. N. (2023). Internet Use, e-Heath Literacy, and Associated Factors in Istanbul, Turkey: A Cross-Sectional Study. *Journal of Consumer Health on the Internet*, *27*(1), 1–11. https://doi.org/10.1080/15398285.2022.2129178

Paul, A. O. (2018). Dealing with Biology Students' Fear of Genetics: Computer Assisted Instruction (CAI) to the Rescue. *Educational Research*, *9*(4), 105–117.

Piraksa, C., Srisawasdi, N., & Koul, R. (2014). Effect of Gender on Student's Scientific Reasoning Ability: A Case Study in Thailand. *Procedia - Social and Behavioral Sciences*, *116*(2014), 486–491. https://doi.org/10.1016/j.sbspro.2014.01.245

Protheroe, J., Whittle, R., Bartlam, B., Estacio, E. V., Clark, L., & Kurth, J. (2016). Health Literacy, Associated Lifestyle and Demographic Factors in Adult Population of an English City: A Cross-Sectional Survey. *Health Expect*, *20*(1), 112–119. https://doi.org/10.1111/hex.12440

Puig, B., Ageitos, N., & Jiménez-Aleixandre, M. P. (2017). Learning Gene Expression Through Modelling and Argumentation. *Science & Education*, *26*(10), 1193–1222. https://doi.org/10.1007/s11191-017-9943-x

Reale, C., Invernizzi, F., Panteghini, C., & Garavaglia, B. (2021). Genetics, Sex, and Gender. *Journal of Neuroscience Research*, *101*(5), 553–562. https://doi.org/10.1002/jnr.24945

Ricciardi, W., & Stefania, S. (2017). New Challenges of Public Health: Bringing the Future of Personalised Healthcare into Focus. *European Journal of Public Health*, *27*(4), 36–39. https://doi.org/https://doi.org/10.1093/eurpub/ckx164

Rodriguez, S., Roter, D., Castillo-Salgado, C., Hooker, G., & Erby, L. (2015). Translation and Validation of a Spanish-Language Genetic Health Literacy Screening Tool. *Health Psychology : Official Journal of the Division of Health Psychology, American Psychological Association*, *34*(2), 120–129. https://doi.org/10.1037/hea0000162

Rujito, L. , Nandhika, T. , Lestari, D. W. D. , Ferine, M. , & Muhaimin, A. (2020). Genetic Literacy Levels and Genetic Screening attitudes on Medical Students in Indonesia: A National Survey. *Malaysian Journal of Public Health Medicine, 20*(3), 1–8. https://doi.org/10.37268/MJPHM/VOL.20/NO.3/ART.407

Rusmana, A., Rachmatullah, A., Nuraeni, E., & Ha, M. (2021). The Genetics Conceptual Understanding of Indonesian and United States Undergraduate Biology Students. *Asia-Pacific Science Education*, *7*, 1–29. https://doi.org/10.1163/23641177-BJA10024

Sadler, T. D., & Donnelly, L. A. (2006). Socioscientific Argumentation: The Effects of Content Knowledge and Morality. *International Journal of Science Education*, *28*(12), 1463–1488. https://doi.org/10.1080/09500690600708717

Saleh, R., Zubaidah, S., & Mahanal, S. (2023). The Correlation between Critical Thinking and Metacognitive Skills on Student Retention Across Genders in Senior High School. *Uniciencia*, *37*(1), 1–20. https://doi.org/https://doi.org/10.15359/ru.37-1.7

Samerski, S. (2014). *Genetic Literacy New Frontiers in Technological Literacy*. Springer. pp 165–172. https://doi.org/10.1057/9781137394750_12

Schmidt, N. A., & Brown, J. M. (2019). *Evidenced-based practice for nurses: Appraisal and application of research* (4th ed.). Jones and Bartlett.

Shea, N. A., Golan Duncan, R., & Stephenson, C. (2015). A Tri-part Model for Genetics Literacy: Exploring Undergraduate Student Reasoning About Authentic Genetics Dilemmas. *Research in Science Education*, *45*(4), 485–507. https://doi.org/10.1007/s11165-014-9433-y

DOI: http://dx.doi.org/10.15359/ru.38-1.9
E-ISSN: 2215-3470

Shi, Y., & Qu, S. (2022). The Effect of Cognitive Ability on Academic Achievement: The Mediating role of Self-Discipline andThe ModeratingRole of Planning. *Frontiers in Psychology*, *13*. https://doi.org/10.3389/fpsyg.2022.1014655

Songsil, W., Pongsophon, P., Boonsoong, B., & Clarke, A. (2019). Developing Scientific Argumentation Strategies using Revised Argument-Driven Inquiry (rADI) in Science Classrooms in Thailand. *Asia-Pacific Science Education*, *5:7*(1), 1–22. https://doi.org/10.1186/s41029-019-0035-x

Sparks, R. A., Jimenez, P. C., Kirby, C. K., & Dauer, J. M. (2022). Using Critical Integrative Argumentation to Assess Socioscientific Argumentation across Decision-Making Contexts. *Education Sciences*, *12*(10), 1–31. https://doi.org/10.3390/educsci12100644

Stern, F., & Kampourakis, K. (2017). Teaching for Genetics Literacy in the Post-Genomic Era. *Studies in Science Education*, *53*(2), 193–225. https://doi.org/10.1080/03057267.2017.1392731

Szadvári, I., Ostatníková, D., & Babková Durdiaková, J. (2023). Sex Differences Matter: Males and Females are Equal but Not the Same. *Physiology & Behavior*, *259*(2023), 1-9: 114038. https://doi.org/10.1016/j.physbeh.2022.114038

Tsaousis, I., & Alghamdi, M. H. (2022). Examining Academic Performance Across Gender Differently: Measurement Invariance and Latent Mean Differences using Bias-Corrected Bootstrap Confidence Intervals. *Frontiers in Psychology*, *13*(2022), 1–12. https://doi.org/10.3389/fpsyg.2022.896638

Van Der Vleuten, M., Jaspers, E., Maas, I., & van der Lippe, T. (2016). Boys' and girls' educational choices in secondary education. The role of gender ideology. *Educational Studies*, *42*(2), 181–200. https://doi.org/10.1080/03055698.2016.1160821

Verdes, A., Navarro, C., & Álvarez-Campos, P. (2021). Mobile Learning Applications to Improve Invertebrate Zoology Online Teaching. *Invertebrate Biology*, *140: e12321*(1), 1–12. https://doi.org/10.1111/ivb.12321

Vlčková, J., Kubiatko, M., & Usak, M. (2016). Czech High School Students' Misconceptions about Basic Genetic Concepts: Preliminary Results. *Journal of Baltic Science Education*, *15*(6), 738–746. https://doi.org/10.33225/jbse/16.15.738

Wang, X., & Cheng, Z. (2020). Cross-Sectional Studies: Strengths, Weaknesses, and Recommendations. *Chest*, *158*(1, Supplement), S65–S71. https://doi.org/10.1016/j.chest.2020.03.012

Wimmer, A., Buzady, Z., Csesznak, A., & Szentesi, P. (2022). Intuitive and Analytical Decision-Making Skills Analysed through a Flow Developing Serious Game. *Journal of Decision Systems*, *31*(sup1), 4–17. https://doi.org/10.1080/12460125.2022.2073863

Wrigley-Asante, C., Ackah, C. G., & Frimpong, L. K. (2023). Gender Differences in Academic Performance of Students Studying Science Technology Engineering and Mathematics (STEM) Subjects at the University of Ghana. *SN Social Sciences*, *3:12*(1), 1–22. https://doi.org/10.1007/s43545-023-00608-8

Wu, H. K., Lee, S. W. Y., Chang, H. Y., & Liang, J. C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education*, *62*, 41–49. https://doi.org/10.1016/J.COMPEDU.2012.10.024

Xin, J., Zhang, Y., Tang, Y., & Yang, Y. (2019). Brain Differences Between Men and Women: Evidence From Deep Learning. *Frontiers in Neuroscience*, *13*(2019), 1–10. https://doi.org/10.3389/fnins.2019.00185

Yoo, Y. S. (2018). Modelling of Factors Influencing Gender Difference in Mathematics Achievement using TIMSS 2011 Data for Singaporean Eighth Grade Students. *Asia Pacific Journal of Education*, *38*(1), 1–14. https://doi.org/10.1080/02188791.2017.1334626

Yu, Z. (2021). The Effects of Gender, Educational Level, and Personality on Online Learning Outcomes during the COVID-19 Pandemic. *International Journal of Educational Technology in Higher Education*, *18:14*(1), 1–17. https://doi.org/10.1186/s41239-021-00252-3

UNICIENCIA Vol. 38, N° 1, pp. 1-26. January-December, 2024 • www.revistas.una.ac.cr/uniciencia • revistauniciencia@una.cr